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CEA-CONF--7527

HIGH-LEVEL WASTE PROCESSING AND DISPOSAL

by

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A paper to be presented at the Plenary Session on the LWR Fuel Cycle at the ANS-ENS International Meeting in Washington, D. C. November 11-16, 1984

SUMMARY

HIGH LEVEL WASTE PROCESSING AND DISPOSAL

High level waste disposal is the only portion of the light water reactor fuel cycle still to be fully demonstrated. No high level nuclear waste has yet been placed in final disposal in any Western country. However, an extensive disposal technology has been developed based on multibarrier containment of high-integrity waste forms in protective geologic structures, and this technology is now being implemented into full-scale disposal facilities.

Without reprocessing, spent LWR fuel itself is generally considered an acceptable waste form. With reprocessing, borosilicate glass canisters containing 40-60% SiO_2, 10-20% B_2O_3, 10-20% alkali oxides and 10-30% waste oxides, have now gained general acceptance as a versatile and effective reprocessing waste immobilization medium. The current first choice for disposal of the high level waste forms is emplacement in an engineered structure in a mined cavern at a depth of 500-1000 meters. A variety of rock types are being investigated including basalt, clay, granite, salt, shale, and volcanic tuff. Some consideration is also being given to seabed disposal.

This paper gives specific coverage to the national high level waste disposal plans for France, the Federal Republic of Germany, Japan and the United States. The French nuclear program assumes prompt reprocessing of its spent fuels, and France has already constructed the AVM, the world's first borosilicate glass waste forms plant, to immobilize high level reprocessing wastes. Two larger borosilicate glass plants are planned for a new French reprocessing plant at La Hague. The French glass plants use a two-step technology in which the wastes are first roasted to oxides in a rotary caliner and then melted with the glass frit in an induction-heated Inconel-bodied melter at 1100°C. France plans to hold the glass canisters in near-surface storage for a forty to sixty year cooling period and then to place them into a mined repository.

The FRG and Japan also plan reprocessing for their LWR fuels. Both are currently having some fuel reprocessed by France, who will deliver back the HLW as borosilicate glass, but both are also planning reprocessing plants which will include waste vitrification facilities. As a prelude to large-scale vitrification, West Germany is now constructing the PAMELA Plant at Mol, Belgium to vitrify high level reprocessing wastes at the shutdown Eurochemic Plant. Similarly, Japan is now operating a vitrification mockup test facility and plans a pilot plant facility at the Tokai reprocessing plant by 1990. Both countries have active geologic repository programs. West Germany is currently strongly considering a salt geology at its Gorleben site, while Japan has a longer range program investigating a number of geologies.

The United States program for high level waste disposal differs from the French, German, and Japanese programs in that it assumes little LWR fuel reprocessing and is thus primarily aimed at direct disposal of spent fuel into mined repositories. However, the United States does have two borosilicate glass plants under construction to vitrify existing reprocessing wastes. These vitrification plants are the DWPF at the Savannah River Defense Plant and the WVDP at the shutdown Nuclear Fuel Services reprocessing plant in West Valley, New York. Both are scheduled for operation in the 1988-9 time frame. Also, both, like the West German and Japanese plants, use slurry-fed, ceramic-bodied melters which are held at about 1100°C by passing an electric current between Inconel electrodes in the molten glass. The multistage United States program for high-level waste repository development is mandated by the Nuclear Waste Policy Act of 1982. In the first stage three candidate mined repositories are to be nominated in 1985, and then narrowed down to a single selection in 1987. In a second stage three additional repositories are to be nominated in 1989, and narrowed down to a single selection in 1990. The first repository is to begin receiving waste in 1998. The commercial power reactors in the United States are being assessed one mil per kilowatt hour to pay for this disposal program.

In summary, high level waste form production is well underway, a variety of geologic repositories are under active investigation, disposal risks are calculated to be very low, and the expected costs of high-level waste disposal at 5-10% of the costs of nuclear electric power are not unacceptable. However, a major political and scientific effort will be necessary to meet institutional requirements to qualify final HLW disposal sites.

THE LIGHT WATER FUEL CYCLE
HIGH LEVEL WASTE PROCESSING AND DISPOSAL

LWR HIGH LEVEL WASTES

High level waste disposal, whether of spent fuel or spent fuel reprocessing discards, is the major unsolved problem for the light-water reactors. In the old phrase from World War II, its situation is hopeless but not serious - hopeless because public fears seem to paralyze long-term solution; not serious because reliable interim storage is in use, and effective technology is available for final disposal.

The magnitude of the problem is illustrated in the first slide. This slide shows the total amount of LWR fuel expected to have been irradiated in France, West Germany, Japan and the United States through the year 2000. The total is about 90,000 tons of heavy metal. Also listed in the slide are the amounts of long-lived fission product radioactivity and of actinides contained in this fuel. Barring major changes in current plans, the United States will dispose of its spent fuel directly, while France, West Germany, and Japan will reprocess. It is assumed that the longer lived fission products will be wastes in either case, but that the reprocessing rejects contain only about 0.5% of the uranium and plutonium in the spent fuel. On these assumptions, the 90,000 tons of irradiated LWR fuel in the year 2000 translate into high-level wastes containing about 45,000 megacuries of fission products with half-life greater than one year plus 40,000 tons of uranium and 500 tons of transuranics. The requirement is to sequester these wastes outside the human environment for a period well in excess of 10,000 years. As shown in Slide 2, the requirement, at least in the United States, is also to reduce the disposal risks perhaps a million times lower than those for any comparable hazards.

DISPOSAL PLANS

Let me emphasize again that no high-level nuclear waste has yet been disposed of in any Western country. However, extensive development work has been performed; scheduled disposal plans are in place; and several plants have been built or are under construction to make disposal forms for high level reprocessing waste.

The basic disposal plans are similar in all Western countries. As described in the third slide, they call for multibarrier containment systems in protective geologic structures. Mined caverns at depths of 500 to 1000 meters are the current first choice for the geology, but some consideration is also being given to seabed disposal in the deep ocean abyssal plains. In either system the only routes by which it is envisioned that the wastes could reach the human environment are human intrusion or water leaching of radionuclides. Both systems therefore provide as their initial barriers a high-integrity waste form and a surrounding waste package designed for mechanical strength, water exclusion, water conditioning and radionuclide containment. In the mined caverns additional barriers are then provided by engineered structures, the cavern geology and a groundwater travel time to the biosphere in excess of 1000 years. For seabed disposal the corresponding barriers are slow turnover and low temperature of the bottom oceanic waters, high absorption by the seabed sediments, and the large dilution of any radionuclides reaching the ocean waters. In both cases difficult accessability makes human intrusion highly unlikely.

The national HLW disposal plans for France, West Germany, Japan, and the United States are shown in Slide 4. France intends to process its LWR fuels three or four years after discharge, vitrify the reprocessing waste into borosilicate glass canisters about a year after that, hold the cannisters in near-surface storage for forty to sixty years, and then place them into a mined repository. The FRG and Japan are currently having some LWR fuels reprocessed by France and the UK, who will deliver back the HLW as borosilicate glass. Both are also operating pilot reprocessing plants, and planning full sizeo plants which will include waste vitrification facilities. West Germany has targeted a mined geologic repository; Japan is also studying mined caverns and, to a lesser extent, seabed disposal. The United States program differs strongly in that it is primarily aimed at direct disposal of spent fuel into mined repositories. These repositories will also accomodate the small amount of LWR reprocessing waste which was produced at the United States West Valley Plant and is scheduled for vitrification in 1988 and 1989.

INTERIM STORAGE

Interim storage is required for the spent fuel, the reprocessing wastes, and, in some cases, the waste forms until they have cooled enough for final disposal. Although requiring constant surveillance, such storage, in water and air-cooled basins or in waste tanks, is well established, well developed, and relatively trouble-free. However, the expected long delays in repository availability - to the year 2000 or later - may require the use of innovative new storage concepts such as the air-cooled transport/storage casks from the Federal Republic of Germany illustrated in Slide 5. The interim storage problem is particularly serious for the older reactors in the United States. These reactors were equipped only with small spent fuel storage basins in the expectation that their fuels would be reprocessed promptly. Failure to accomodate their wastes could shut the reactors down. Hence the United States is also considering a Monitored Retrievable Storage Facility.

WASTE PACKAGES

Once the wastes are ready to come out of interim storage, the next step is to package them for disposal. Typical - or perhaps extreme - packaging requirements have been set by the United States Nuclear

Regulatory Commission in 10 CFR 60. These rules, shown in Slide 7 require that the waste package permit retrieval while the respository is open, exclude groundwater inleakage "absolutely" for 300-1000 years, and then restrict outleakage to one part in 100,000 of the 1000-year inventory for a period of 10,000 years.

SPENT FUEL DISPOSAL PACKAGES

Because the LWR fuels are fabricated to retain their integrity under severe reactor conditions, they are usually considered to be their own waste form. The fuel clusters are dissembled to reduce volume and remove inert components such as end fittings; the fuel rods are then bundled together and put in a suitable protective package. Slide 7 is an example of such a disposal package taken from the U. S. salt repository program. The complexity and expense of the package will depend on the credit given the spent fuel as a waste form and on the repository type. In the Swedish nuclear waste program, for example, which was abruptly required by law to give assurance that adequate disposal of spent fuel is possible or face immediate shutdown of all Swedish power reactors, there was little time for repository or waste form development. The successful feasibility demonstration by necessity relied primarily on very high integrity - and very expensive - thick copper waste canisters.

REPROCESSING WASTE FORMS - BOROSILICATE GLASS

Compositions of French, German and Japanese high-level reprocessing wastes are listed in Slide 8. Unlike spent fuel, these wastes are disperable solutions, salts, and sludges, and have to be immobilized into high integrity solids before they can be placed in a repository. A large number of solidification forms have been investigated for these wastes, but over the past few years Belgium, Britain, Canada, France, India, Italy, Japan, West Germany, and the United States have unanimously adopted borosilicate glass as the immobilization medium. The reasons are listed in Slide 9. Borosilicate glass will accept essentially all nonvolatile waste radionuclides, can be formed in a one- or two-step process using well-developed technology, and, under the proper conditions, can itself reduce radionuclide releases to less than a one part in 100,000 per year. Typically the borosilicate waste glasses contain 40-60% SiO_2, 10-20% B_2O_3, 10-20% alkali oxides, and 10-30% waste oxides. As listed in Slide 10, borosilicate glass plants are now at the production stage; hence I will devote a good share of the talk to them.

France, who built the first and so far only production plant for high-level waste forms, uses a two-step process to produce borosilicate glass canisters. As illustrated in Slide 11, the first step consists of a rotory calciner which roasts the wastes at about 600°C to a mixture rich in oxides, while the second step melts these oxides with about twice as much glass frit. The melting is performed at about 1100°C in an induction-heated Inconel melter, which pours the glass into stainless-steel canisters one meter high and half a meter in diameter. The original AVM, as pictured, has to date produced over 1000 waste canisters and is still in use. Two larger AVH systems of the same general design with a capacity, in three lines, of about 1800 kg of glass a day are under construction for the French spent fuels reprocessing plant at La Hague. Great Britain is also building an AVM type plant for startup in 1987, while Belgium and Italy are considering such plants.

Japan, West Germany, and the United States are in various phases of construction on waste form plants which use a one-step process to produce the borosilicate glass. In these plants waste slurry and glass formers are poured directly onto the top of a molten glass pool in a continuous melter, evaporating off both free and combined water from the slurry and dissolving the resultant waste oxides into the glass. The melter for the Defense Waste Processing Facility (DWPF) now under construction in the United States to begin operation in 1989 is typical. This melter, illustrated in Figure 12, operates at about 1150°C, has a ceramic body and is electrically, or Joule, heated by immersing Inconel electrodes in the molten glass and passing an electric current through the glass.

A large continuous melter will produce about 1500 kg of waste glass a day with an average waste residence time in the melter of about two days. Much larger melters of nearly identical basic design are in routine use in the glass industry. However, the need to handle - and contain - very large amounts of radioactivity in the waste melters greatly increases the size and complexity of the melter support systems. Thus, a waste melter system will typically cost ten times as much as a larger commercial glass system. The large DWPF glass forms plant is budgeted at $800 million.

The first requirement for all the radioactive melters is remote operation and maintenance behind shielding and containment walls. Slide 13 is a photograph of a remote-handled vitrification cell mockup. This cell is to go in the PAMELA Plant now under construction by the FRG at Mol, Belgium to vitrify high-level wastes from the shutdown Eurochemic Plant. The complexity is obvious. Provisions must be included for remote operation, remote sensing, quality control, and, above all, remote maintenance in items such as replacing a worn out melter.

The second requirement for the radioactive melters is containment. Large amounts of water must be boiled off the waste slurries, and some of the radionuclides must be heated above their volatilization point, but the ratio between radioactivity handled and radioactivity released must be something like ten billion. An elaborate offgas system is thus required. Slide 14 shows the system from the Japanese Mockup Test Facility for the Tokai Vitrification Pilot Plant. The arrangement consists of a dust scrubber and condenser section to cool the offgas and percipitate the volatiles, particle separators, washer and scrubbers, ruthenium absorber, and filter sections exhausting through a stack. A particular problem is to make sure that the glass formers in the offgas do not solidify in the offgas lines so as to clog the system.

The borosilicate glass waste forms are normally cast in stainless-steel, iron, titanium or other leak-tight canisters; they can be further packaged with overpacks and conditioning materials. In a mined repository they will also normally be surrounded with backfill. The outer packagings can greatly reduce the possibility of radionuclide release. They can also provide the detailed match between the waste form and the repository. This match may have to be quite specific since it has, for example, been shown that packaging materials such as lead and aluminum can passivate the waste forms under some repository conditions while other materials such as bentonite and iron might increase corrosion if used under improper conditions. Since saturation effects in the very restricted amounts of groundwater in the geologic repositories can greatly retard radionuclide releases from the waste forms, crushed nonradioactive glass with the same chemical composition as the waste forms makes a particularly attractive backfill material.

WASTE FORM TRANSPORT

Up to here we have largely discussed technical problems. Waste form transport from the fabrication plant to the repository begins to enter the political arena. As illustrated in Slide 15, transport casks for spent fuel are well developed. They are also easily adapted to carry reprocessing waste forms instead of fuel merely by designing the appropriate insert. The spent fuel casks have an excellent record in actual service, are required to pass rigorous tests for licensing, and have come through unscathed in a series of railroad crashes, gasoline fires and other severe accident simulations at the Sandia Laboratories and elsewhere. The difficulty is that, particularly in the United States, some local communities can be expected to raise strong objections to passage of the casks through their juristrictions. These objections could be used as a means of stopping high-level waste disposal and hence eventually light-water reactor operation.

WASTE REPOSITORIES

The hopefully-facetious situation-hopeless rating at the beginning of the talk was, however, assigned largely because of the unwillingness of most localities to accept a waste repository in their area. The situation-not-serious rating was given largely because experience with natural ore bodies and with the fossil natural fission reactors discovered near Oklo in the African Congo indicate that any reasonable geology gives good assurance of excellent radionuclide containment.

Slide 16 is a diagram of a conceptual mined geologic repository. The repository consists of several vertical shafts giving access to a series of mined tunnels at a depth of 500 to 1000 meters. Holes bored into the rock at the bottom or sides of the tunnels accomodate the waste canisters, which are backfilled over and capped with a shielding plug. Mechanical considerations limit the closest spacing between the waste holes to 1-2 meters, while temperature limits restrict the heat loading in the repository to 100-200 kilowatts per hectare depending on the geology being used. Reference United States repository designs are for a mined area of about 1000 hectares accomodating the wastes from about 70,000 MTHM LWR fuel.

Slide 17 summarizes the repository development programs for France, West Germany, Japan, and the United States. France is looking primarily at salt, granite, and clay as respository geologies. West Germany has a target date of the 1990s and is currently most strongly considering salt at its Gorleben site as the geologic medium. Japan is investigating mined repositories in granite, diabase, shale, zeolitic tuff, limestone, slate and schist with a target date of 2000 for trial disposal. Japan, along with most other countries, also has a small program on seabed disposal. In the United States a very detailed multi-stage repository program is outlined in the Nuclear Waste Policy Act of 1982. In the first stage three candidate repositories are to be nominated in 1985, and then narrowed down to a single selection in 1987. In a second stage three additional repositories are to be nominated in 1989, and narrowed to a single selection in 1990. The first repository is to begin receiving waste in 1998. The commercial reactors in the United States are being assessed one mil per kilowatt hour to pay for this disposal program. Estimated costs for the United States repositories are 1-2 billion dollars each. Primary geologies being investigated are basalt, bedded salt, domed salt, and volcanic tuff, with hard rock, e.g. granite, to be added in the second stage. Experimental facilities in basalt, salt and tuff respectively exist at the Hanford site in Washington, WIPP in New Mexico and the Nevada Test Site.

SUMMARY

Conclusions from the talk are given on the last slide. The first conclusion is that an excellent technology already exists for high-level waste disposal. With appropriate packaging spent fuel seems to be an acceptable waste form. Borosilicate glass reprocessing waste forms are well understood, in production in France, and scheduled for production in the next few years in a number of other countires. For final disposal a number of candidate geological repository sites have been identified and several demonstration sites opened. The second conclusion is that adequate financing and a legal basis for waste disposal are in place in most countries. Costs of high-level waste disposal will probably add about 5-10% to the costs of nuclear electric power. The third conclusion is less optimistic. Political problems remain formidable in highly conservative regulations, in qualifying a final disposal site, and in securing acceptable transport routes.

SLIDE 1

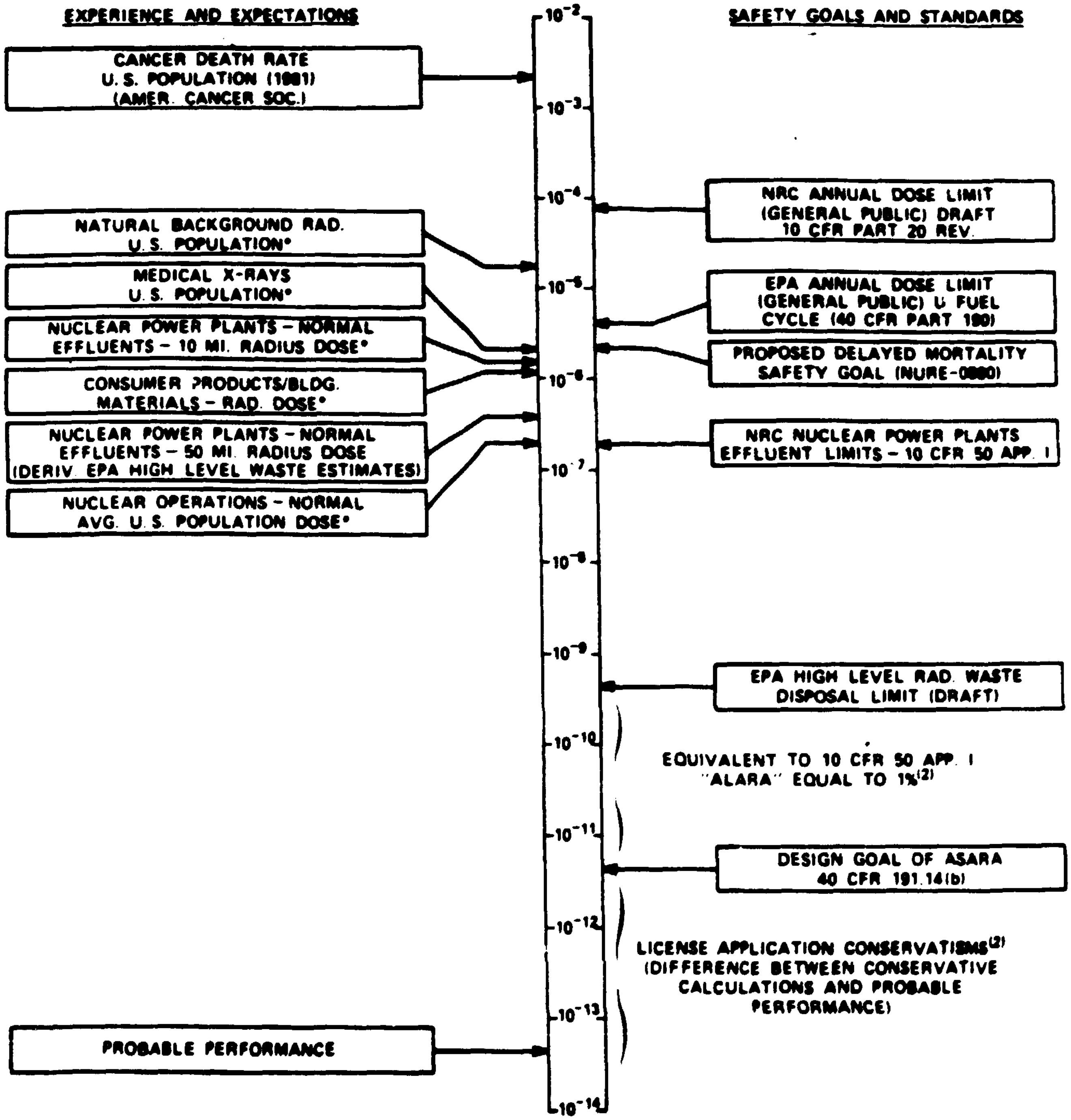
HIGH LEVEL WASTE FROM LWR FUEL IRRADIATION

CUMMULATIVE TO YEAR 2000

	METRIC TONS HEAVY METAL IRRADIATED		MEGACURIES LONG LIVED FISSION PRODUCTS	METRIC TONS ACTINIDES PRODUCED	
	RECYCLE	WASTE	WASTE	RECYCLE	WASTE
FRANCE	23,000	45	12,000	260	20
GERMANY (FRG)	7,200	36	4,000	80	4
JAPAN	19,600	114	7,800	220	10
UNITED STATES	39,800	39,800	21,000	-	470
TOTAL WASTE		39,995	44,800		504

INDIVIDUAL DELAYED MORTALITY (CANCER)

RISK/YEAR



*BEIR III

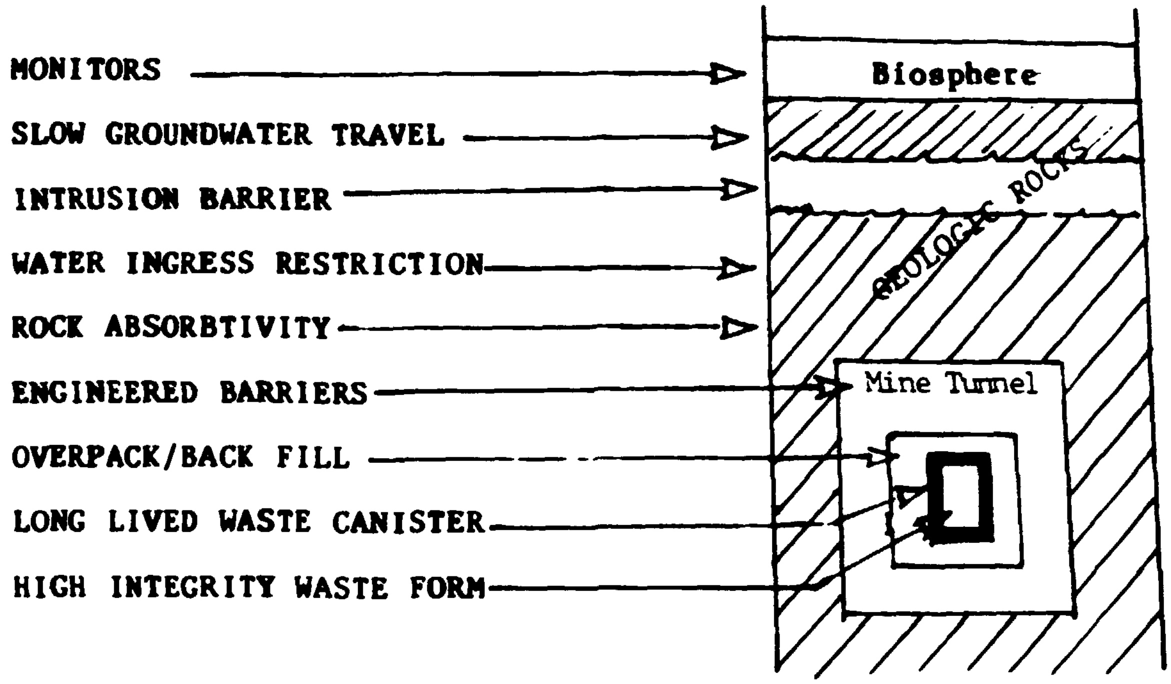
SOURCES: (1) EPRI PRESENTATION EPA-SAB SAN FRANCISCO MARCH 24, 1983
(2) EEI TESTIMONY EPA PUBLIC HEARING WASHINGTON, DC MAY 12, 1983

COMPARATIVE RISKS OF HIGH-LEVEL WASTE DISPOSAL UNDER U. S. REGULATORY REQUIREMENTS

SLIDE 2

SLIDE 3

MULTIBARRIER CONTAINMENT FOR HLW DISPOSAL
MINED GEOLOGIC REPOSITORY



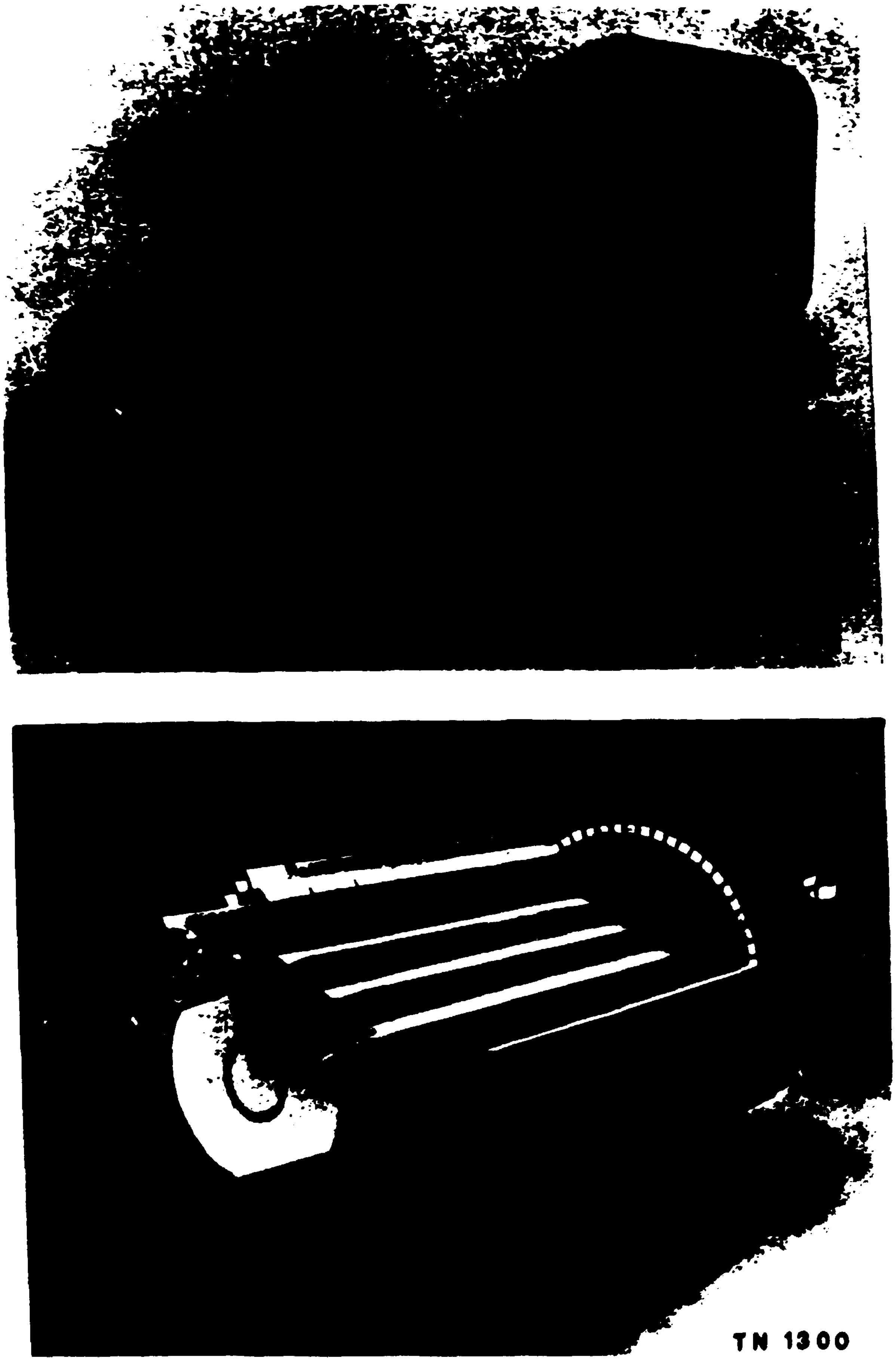
SLIDE 4

NATIONAL PLANS FOR HIGH LEVEL WASTE DISPOSAL

LIGHT WATER REACTOR FUELS

	FRANCE	FRG	JAPAN	USA
REPROCESS FUEL	YES	YES	YES	NO
WASTE FORM	GLASS	GLASS	GLASS	SPENT FUEL
FIRST WASTE FORM PLANT	1978	1992	1992	1988*
REPOSITORY	GEO.	GEO.	GEO.	GEO.
REPOSITORY STARTUP	~ 2000	~ 2000	~ 2000	1998

*WEST VALLEY VITRIFICATION PLANT FOR EXISTING REPROCESSING WASTE



AIR-COOLED TRANSPORT/STORAGE CASKS
FOR LWR SPENT FUEL

SLIDE 5

SLIDE 6

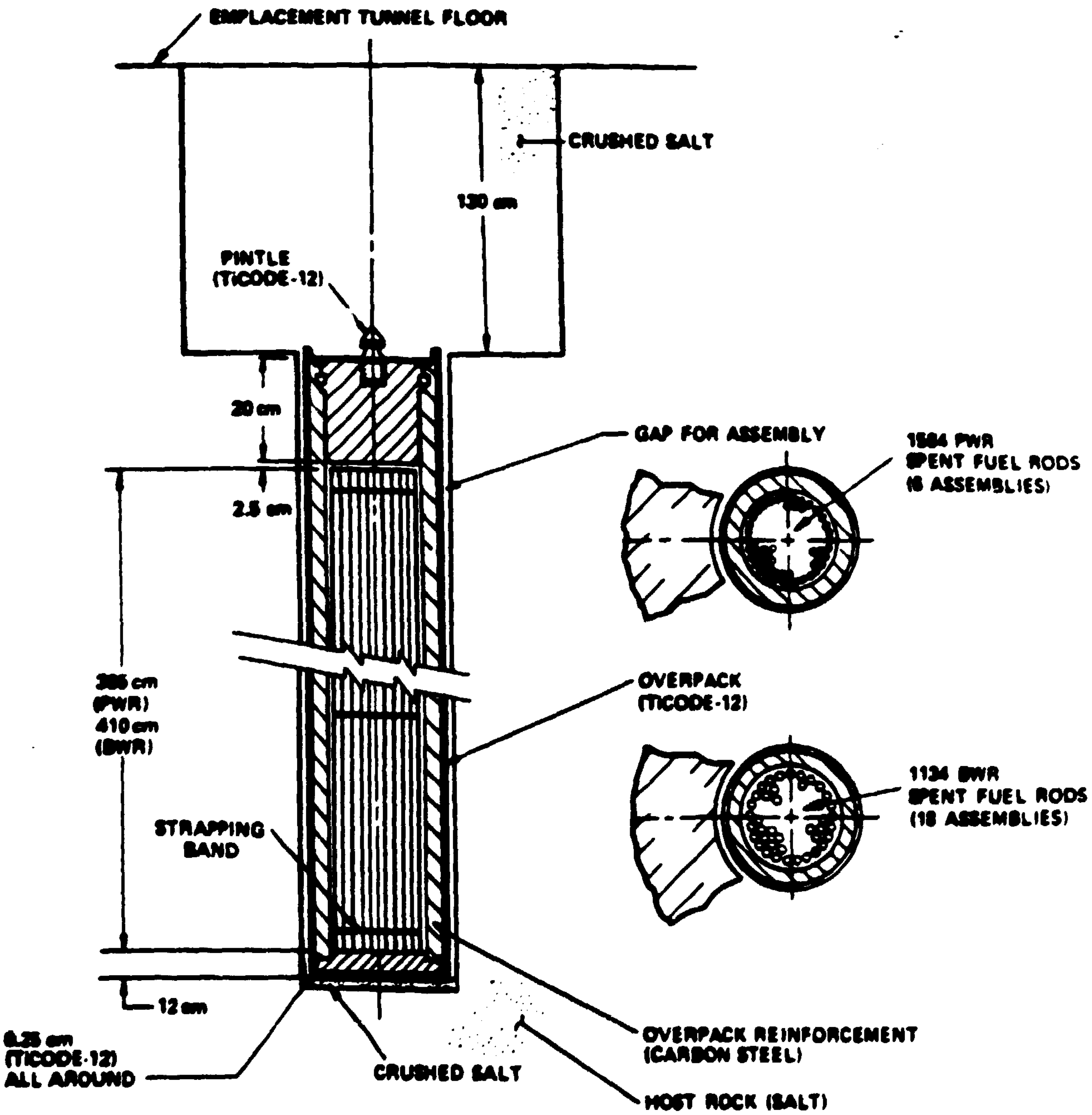
U. S. HIGH-LEVEL WASTE REGULATIONS

NUCLEAR REGULATORY COMMISSION - 10 CFR 60

- WASTE RETRIEVABLE UNTIL REPOSITORY CLOSED
- 300-1000 YEAR CONTAINMENT BY WASTE PACKAGE
- RELEASE <1 PART IN 100,000 AFTER CONTAINMENT
- >1000 YEAR GROUNDWATER TRAVEL TO ACCESSIBLE ENVIRONMENT

ENVIRONMENTAL PROTECTION AGENCY - 40 CFR 191 (DRAFT 5/21/84)

- BEFORE REPOSITORY CLOSURE, INDIVIDUAL DOSE TO PUBLIC <25 MR WHOLE BODY
- AFTER CLOSURE, RELEASES TO ACCESSIBLE ENVIRONMENT SHALL NOT EXCEED LIMITS CONSERVATIVELY ESTIMATED BY EPA TO PRODUCE 1000 HEALTH EFFECTS IN 10,000 YEARS FROM 100,000 MTHM FUEL IRRADIATION
- AS LOW AS REASONABLY ACHIEVABLE



CONCEPTUAL SPENT FUEL DISPOSAL CANISTER
SALT REPOSITORY (REF. - ONWI 438)

SLIDE 7

SLIDE 8

LWR HIGH-LEVEL REPROCESSING WASTE COMPOSITIONS

	FRANCE UP-2	GERMANY (FRG) WA-350	JAPAN
VOL HLLW/TON FUEL, L/MT	300*	800	300-1000
AGE AT VITRIFICATION, YEARS	4-6	4-6	5-6
FREE ACIDITY, HNO_3,M/L	2	5	2-7
FISSION PRODUCTS, KG/MWD	26	35	30
ACTINIDES, KG/MT	1.48	5.3	7.5
CORROSION PRODUCTS, KG/MT	8.3	2.6	7.2
ACTIVITY, MC/MT	0.53	0.46	~0.5

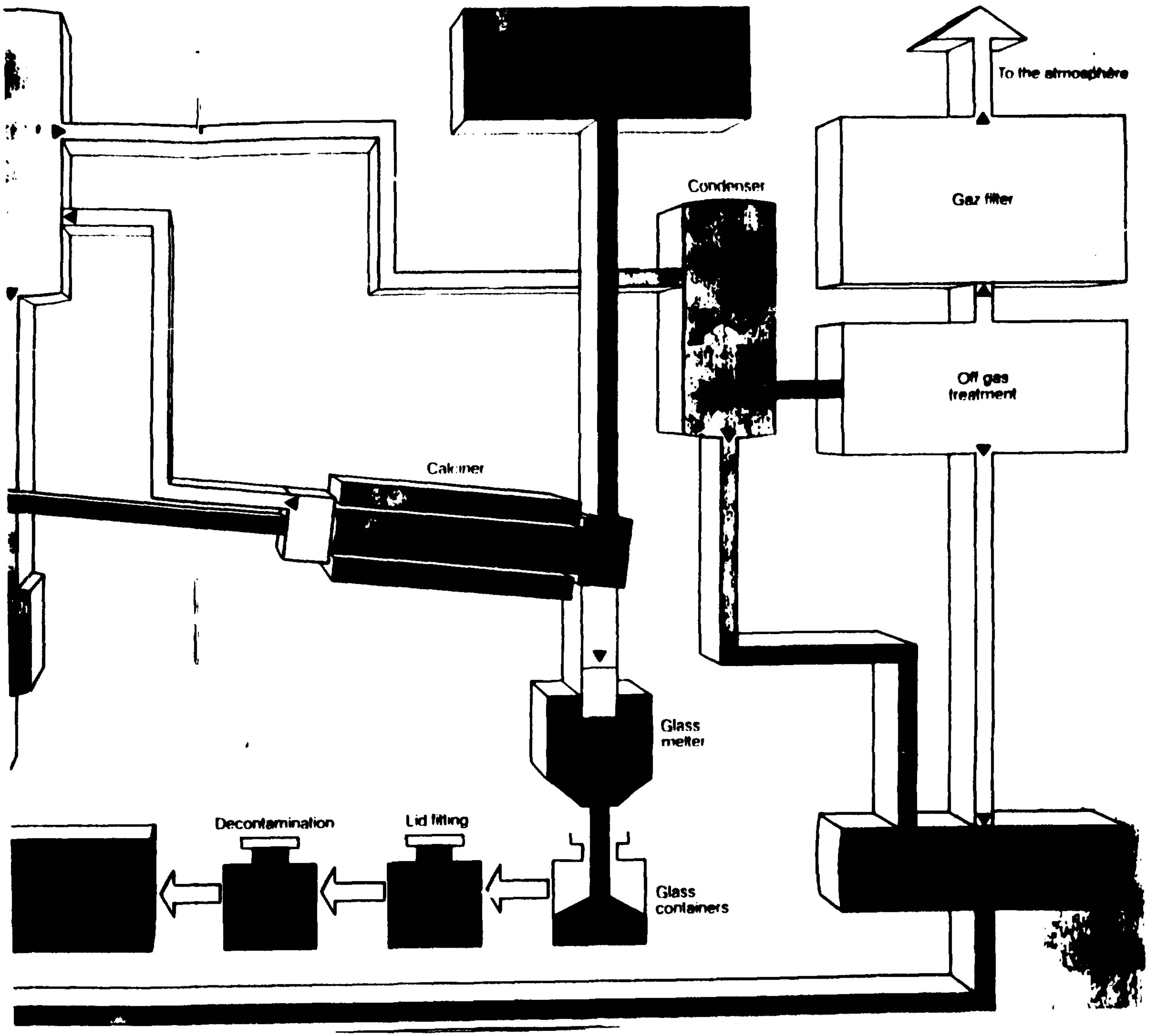
*MIXED WITH 198 L/MT SOLVENT WASH AND 135 L/MT DISSOLVER FINES SLURRY BEFORE DISPOSAL

SLIDE 10

HLW BOROSILICATE GLASS PLANTS

COUNTRY	LOCATION	TYPE	NAME	OPERATIONAL
BELGIUM	MOL	CER. MELTER	PAMELA	1985
	MOL	AVM, 1 LINE	AVB	1989?
FRANCE	MARCOULE	AVM, 1 LINE	AVM	1978
	LA HAGUE	AVM, 3 LINE	AVH-R7	1986
	LA HAGUE	AVM, 3 LINE	AVH-T7	1989
GERMANY (FRG)	T.B.D.	CER, MELTER	WA-350	1992
INDIA	TARAPUR	POT	WIP	1982
ITALY	TRISAIA	POT	IVET-2	1988?
JAPAN	TOKAI	CER. MELTER	VPP	1992
UK	WINDSCALE	AVM, 2 LINE	WVP	1987
USA	WEST VALLEY	CER. MELTER	WVDP	1988
	SAV. RIVER	CER. MELTER	DWPF	1989
	HANFORD	CER. MELTER	HWVP	1990?

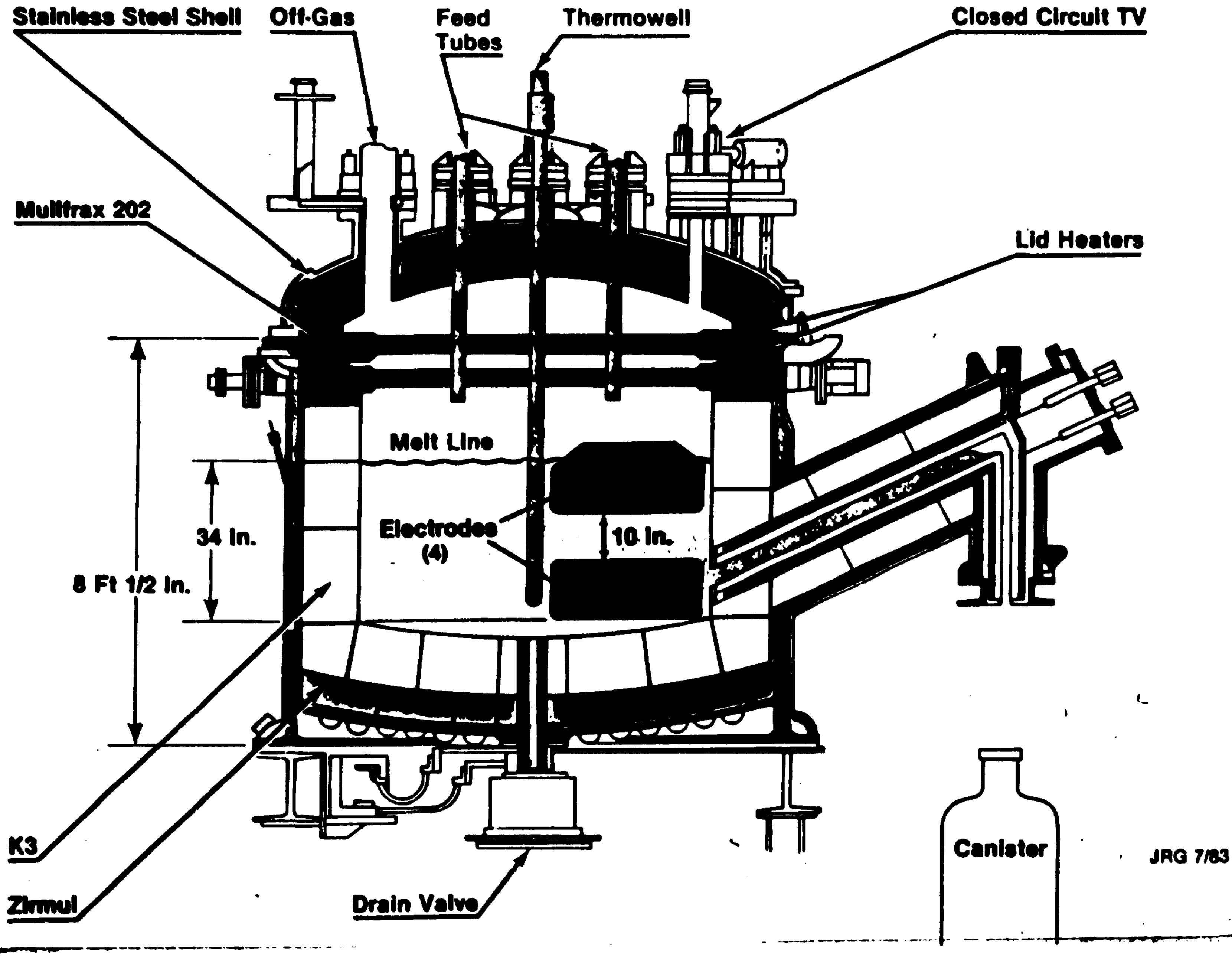
SLIDE 11



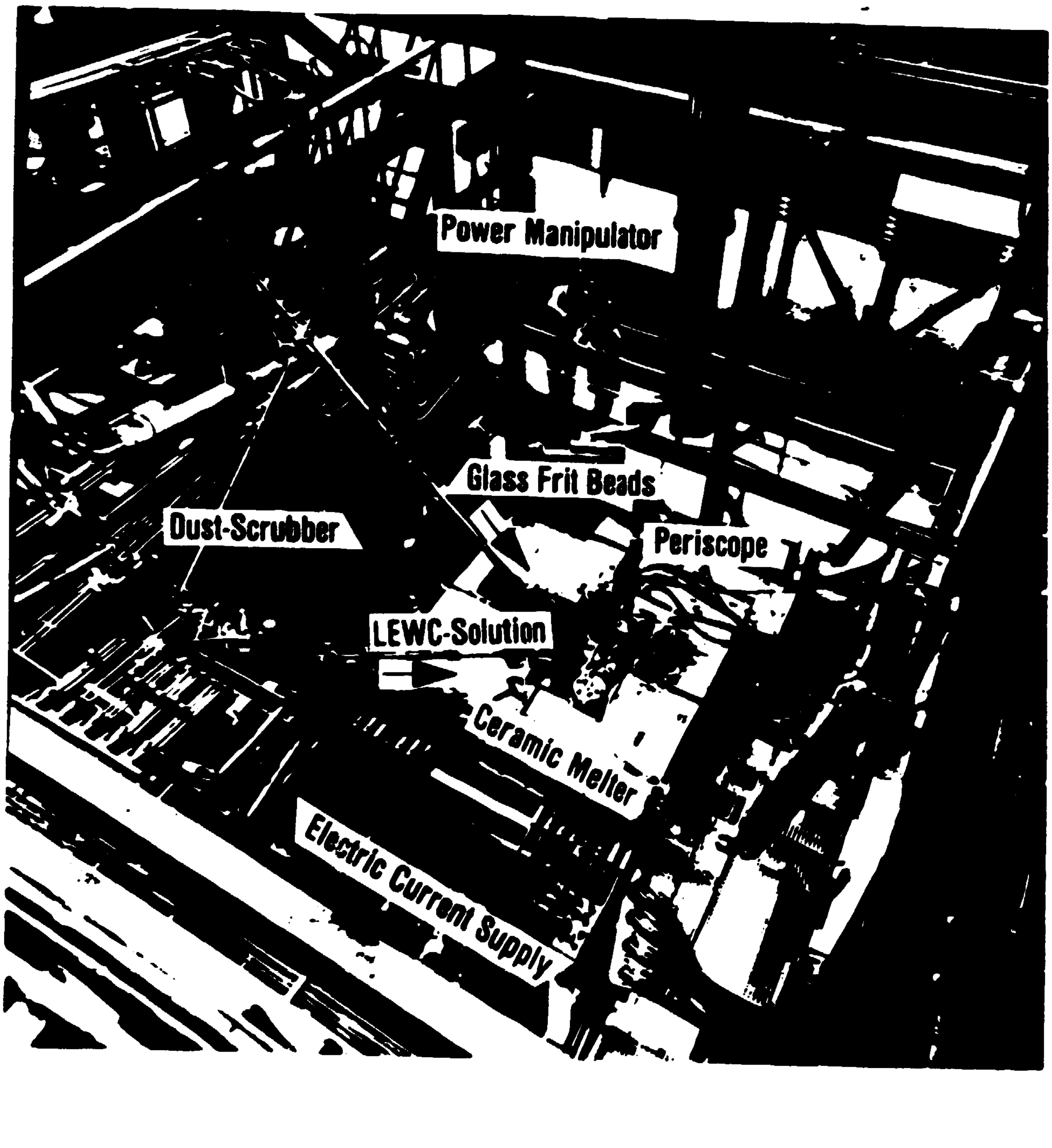
To the atmosphère
Gaz filter
Condenser
Off gas treatment
Calciner
Glass melter
Decontamination
Lid fitting
Glass containers

SLIDE 12

DWPF Melter

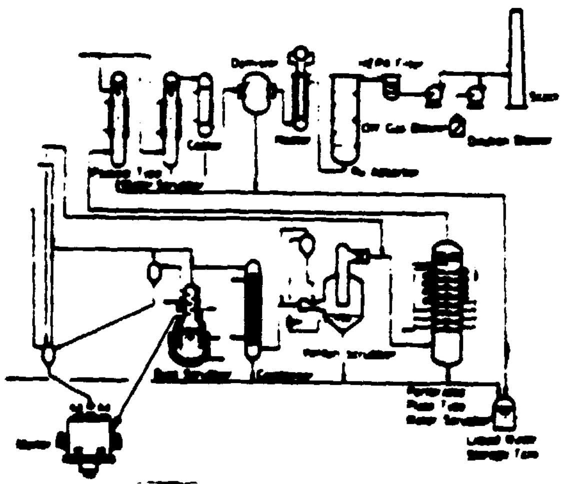


SLIDE 13



Power Manipulator
Glass Frit Beads
Dust-Scrubber
Periscope
LEWC-Solution
Ceramic Melter
Electric Current Supply

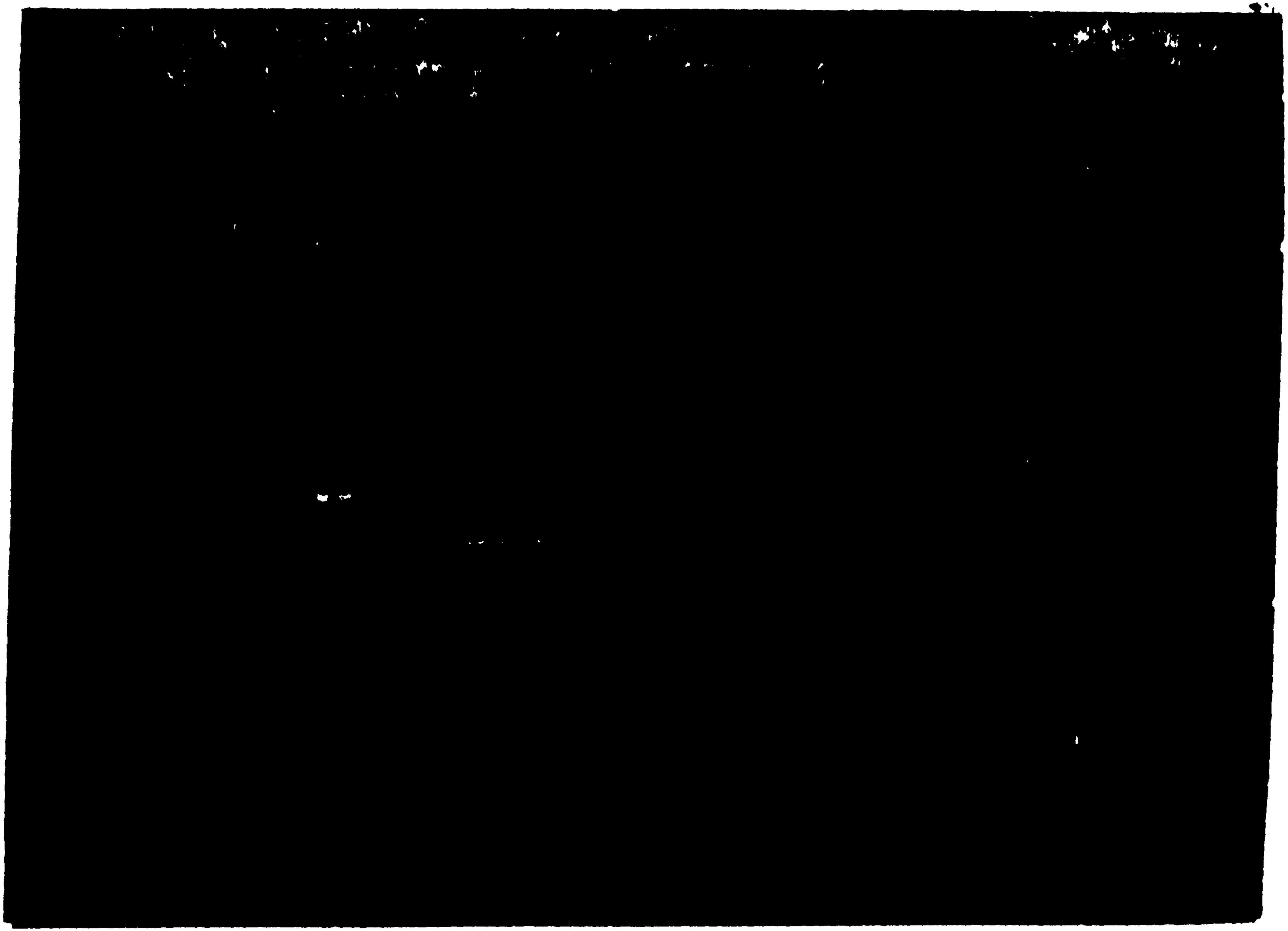
Being Redrawn



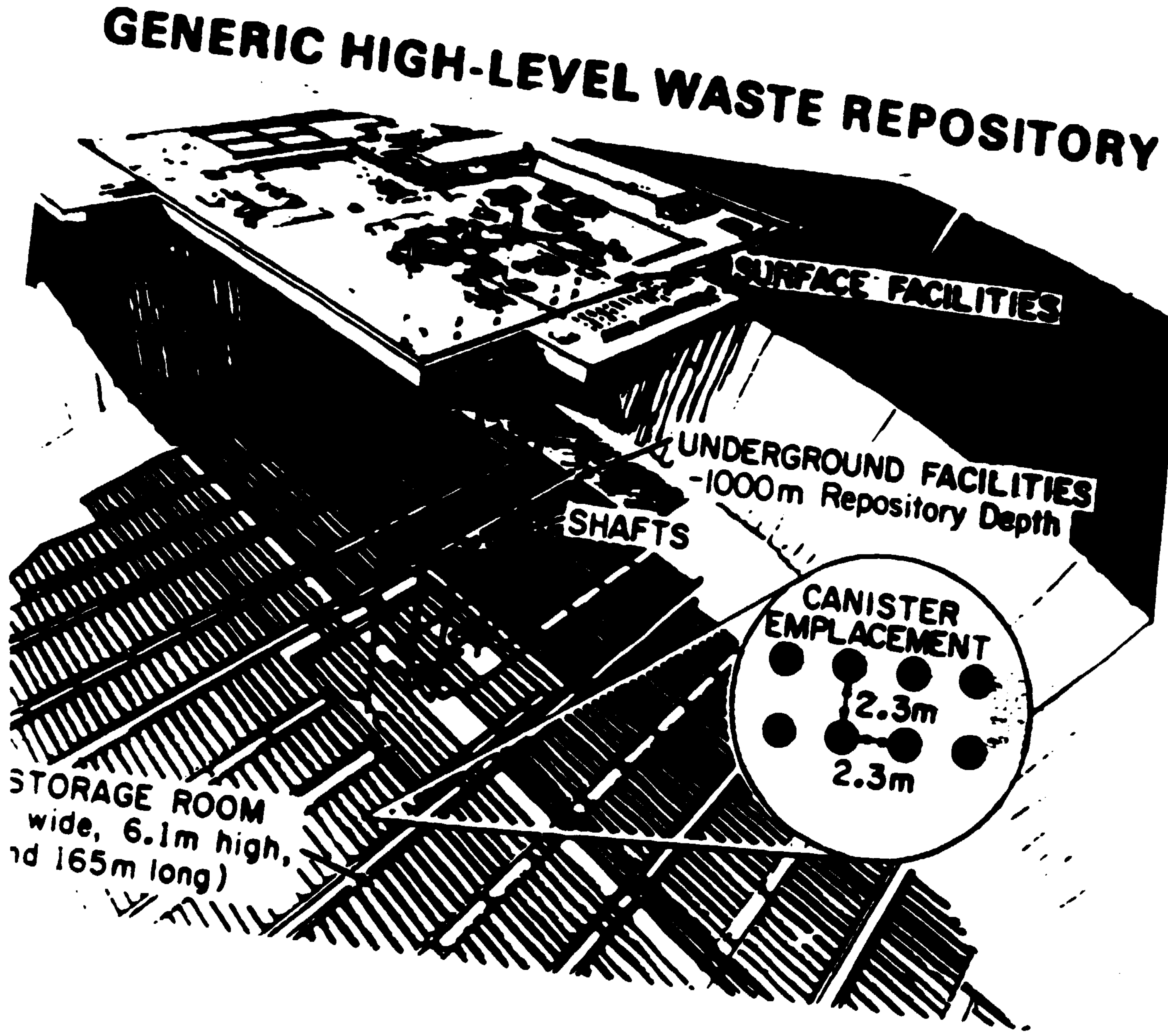
GLASS MELTER OFFGAS SYSTEM
MOCKUP TEST FACILITY FOR TOKAI VITRIFICATION PILOT PLANT

SLIDE 14

SLIDE 15



NLI 10/24 SPENT FUEL CASK


GENERIC HIGH-LEVEL WASTE REPOSITORY
SURFACE FACILITIES
UNDERGROUND FACILITIES
-1000m Repository Depth
SHAFTS
CANISTER
EMPLACEMENT
2.3m
2.3m
STORAGE ROOM
wide, 6.1m high,
nd 165m long)

SLIDE 16

SLIDE 18

SUMMARY

LWR HIGH-LEVEL WASTE DISPOSAL

HIGH INTEGRITY WASTE FORMS ARE AVAILABLE NOW

- SPENT FUEL PACKAGES
- BOROSILICATE GLASS CANISTERS

MINED REPOSITORIES ARE SCHEDULED FOR THE YEAR 2000

- BASALT, CLAY, GRANITE, SALT, TUFF UNDER TEST
- CALCULATED CONTAINMENTS EXCELLENT

HLW DISPOSAL COSTS ARE 5-10% OF NUCLEAR ELECTRIC COSTS

- U. S. ASSESSING 1 MIL/KW-HOUR

POLITICAL OBSTACLES REMAIN FORMIDABLE

- HIGHLY CONSERVATIVE REGULATIONS
- LOCAL OPPOSITION TO SHIPMENTS, REPOSITORIES